NOAA FISHERIES

Northwest Fisheries Science Center

9.0 Evolution and Life-History Overview

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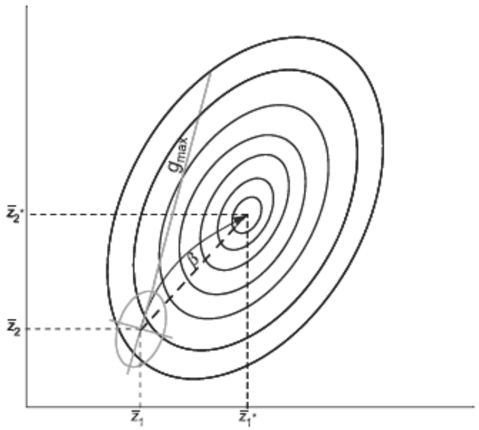
What is life-history evolution?

- Genetic change in age & size at maturity, lifespan & reproductive investment, offspring number & quality, and the schedule and seasonal timing of these transitions
- A key objective is to understand how genetic diversity and natural selection influence fitness and resilience
- We combine genetic tools such as GWAS and pedigree reconstruction with tools from physiology and ecology: e.g., life cycle models, PVAs, and IPMs

Evolution toward a fitness peak

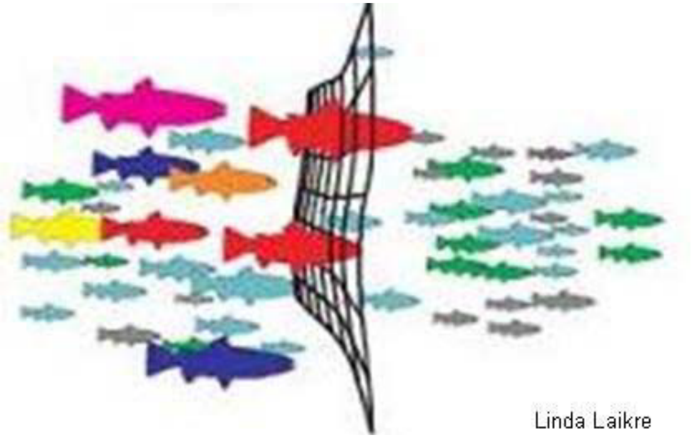


Naish & Hard (2008)

Why is life-history evolution important?

- An organism's life history reflects the environmental factors it has adapted to in its natural habitat

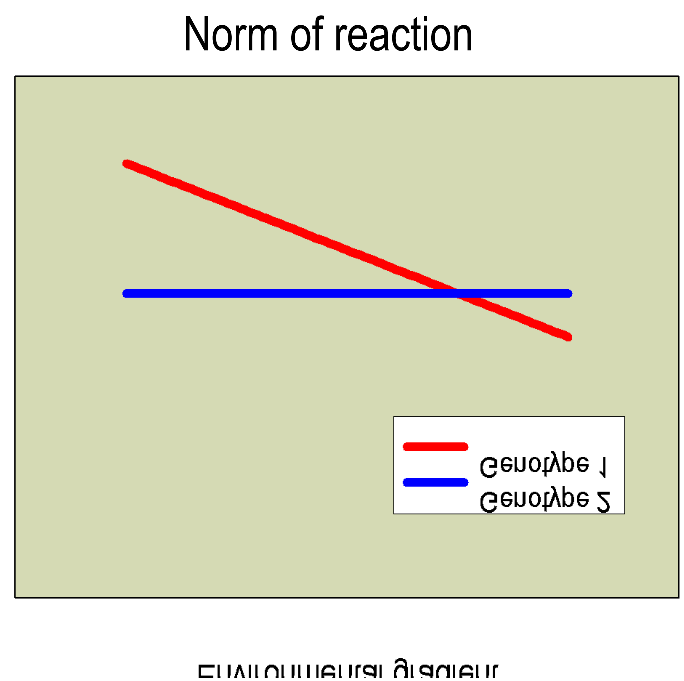
- Abrupt, persistent life-history changes in response to selective pressures can affect productivity and viability



- Evolutionary responses to relaxation of selective pressures might occur more slowly ("Darwinian debt")
- Is it acceptable to also human-mediated selection in protected species?

How is it relevant to protected species?

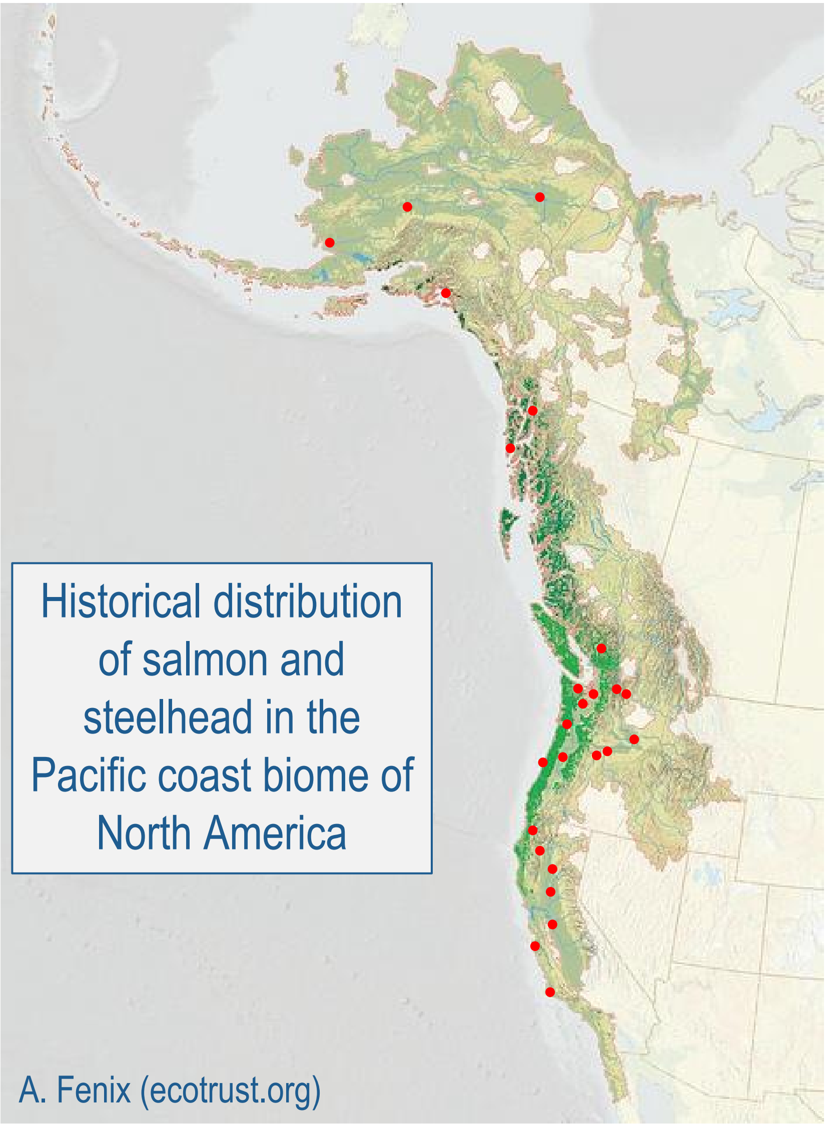
- Anthropogenic changes to ecosystems protected species depend upon are likely to change their life histories
- These changes reflect adaptations away from historical patterns forged by natural selection
- Changes may involve phenotypic plasticity (GxE) if cue is reliable
- Genetic changes can occur on time frames relevant to conservation and management



NOAA's life-history work on protected species

- Research at both Centers focuses on characterizing factors that influence life-history expression
- You'll hear about a variety of studies aimed at understanding key facets of salmonid life history
- Additional work at both Centers is examining other relevant topics in salmonid life history:
  - Genomics and epigenomics of life history strategies
  - Selection on size and phenology, reproductive success
  - Partial anadromy in *Oncorhynchus mykiss*
  - Plasticity in maturation, smoltification and migration
  - Variation in habitat use and migratory behavior

Geographic scope of NOAA's life-history work



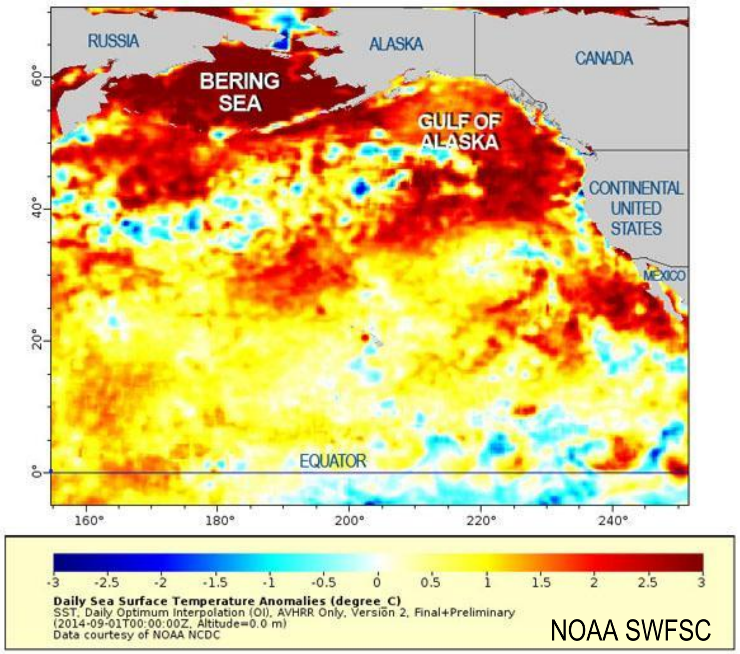
- Research on salmon and steelhead life history at the Northwest and Southwest Fisheries Science Centers covers much of the range of these species' historical distributions
- Focus is on anadromous populations in California, Idaho, Oregon, and Washington
- Some studies in Alaska

Three examples for protected species

1. Evolutionary demography of steelhead
    - All listed steelhead DPSs have resident fish
    - Conclusions about viability of steelhead DPSs depend on how one considers resident fish
2. Effects of the Columbia River hydropower system on salmon life history
    - Changes in selective regimes from pristine rivers to a series of reservoirs connected with bypass facilities
    - Millions spent on minimizing the lethality of dams to salmon, but little spent on evaluating *which* fish survive

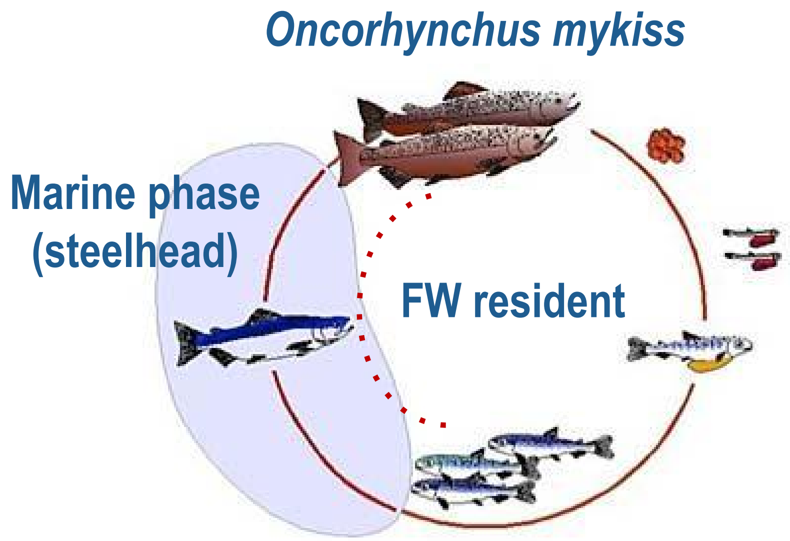
Three examples for protected species

3. Consequences of climate change for salmon
   - Likely to alter seasonal timing of reproduction and migration away from optima
   - Could increase extinction risk or yield range shifts
   - Capacity to respond depends on genetic diversity in life history and the nature of climate change selection



The hybrid migratory strategy of *O. mykiss*

- Growth, size at age and morphology influence migratory trajectories
- These traits are heritable and map to genomic sites known to be associated with migration propensity
- Resident and migratory paths may be canalized

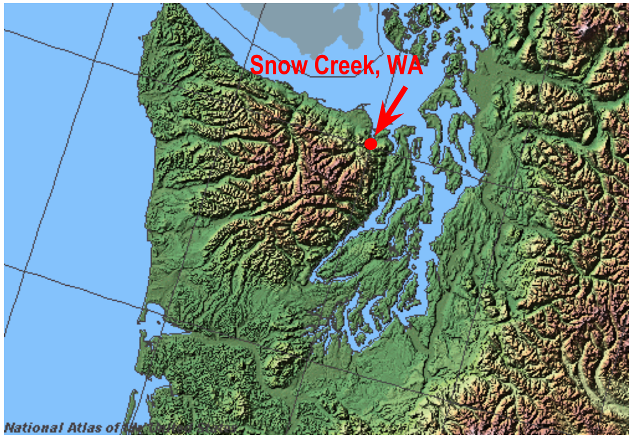


NWFSC Fish Ecology Division

- How do residents contribute to viability of anadromous populations? Can resident fish help to conserve steelhead?

Steelhead life history in two coastal streams

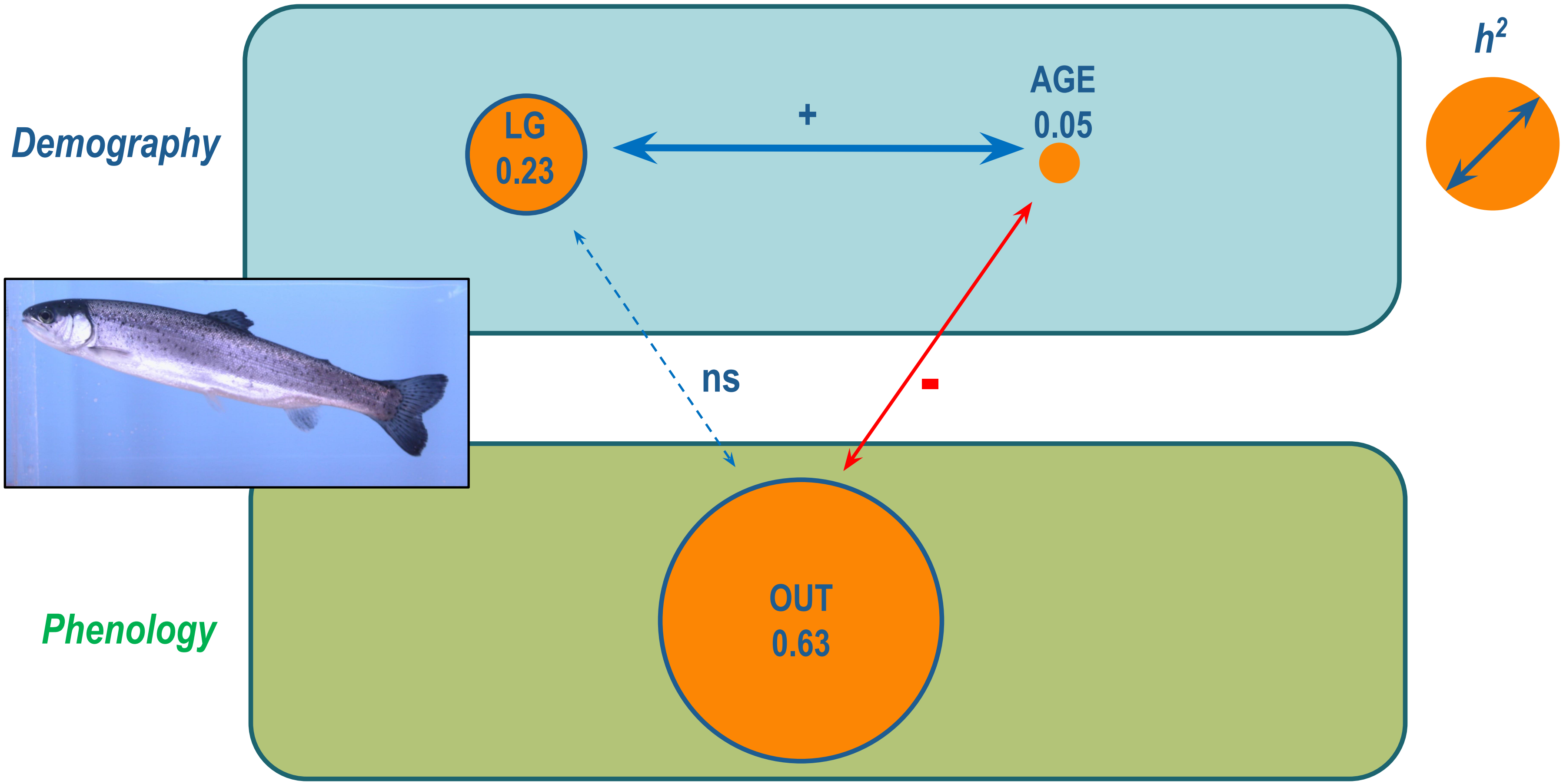
- Different solutions to a problem
- Residents produce seaward migrants; steelhead can produce residents
- Disparate age structures
- Low rates of iteroparity



	Snow Creek	Sashin Creek
Age structure		
Age 3	4%	0%
Age 4	87%	36%
Age 5	9%	53%
Age 6	0%	11%
Demography		
Smolts/spawner	30	13
Marine survival	5%	11%
Recruits/spawner	1	1
Iteroparity	2%	5%

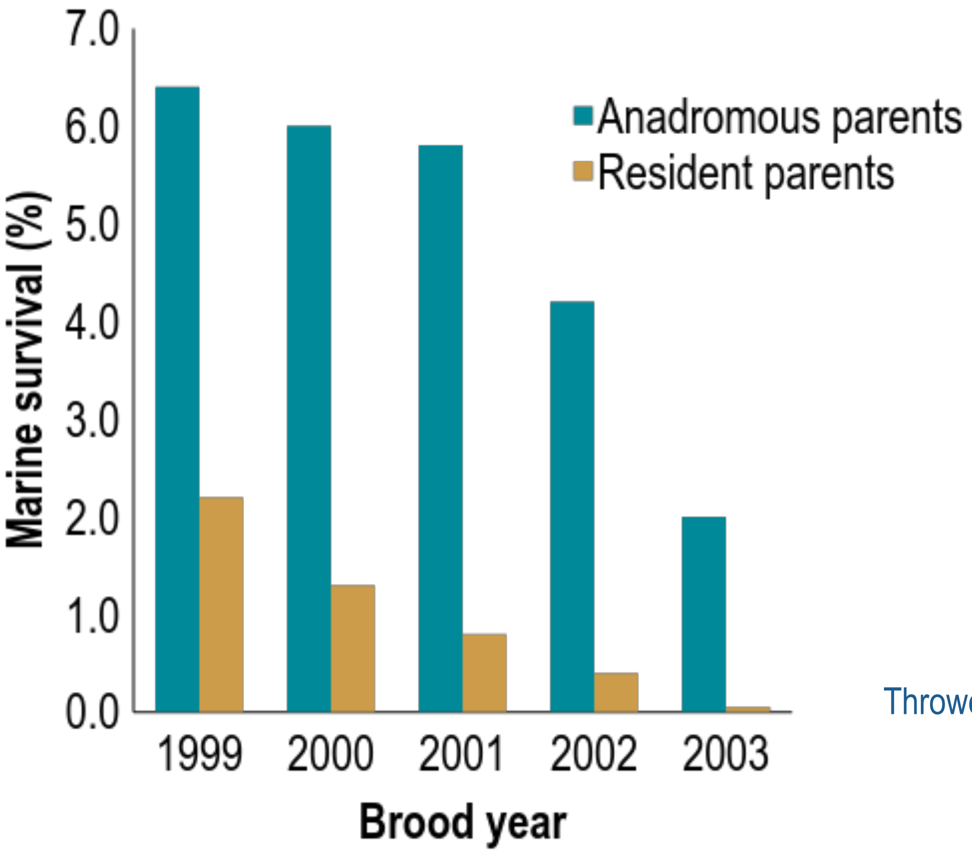
adfg.alaska.gov

Size and migration timing of steelhead smolts



- Smolt length (LG) and migration timing (OUT) are heritable but uncorrelated
- Older smolts are larger and leave earlier

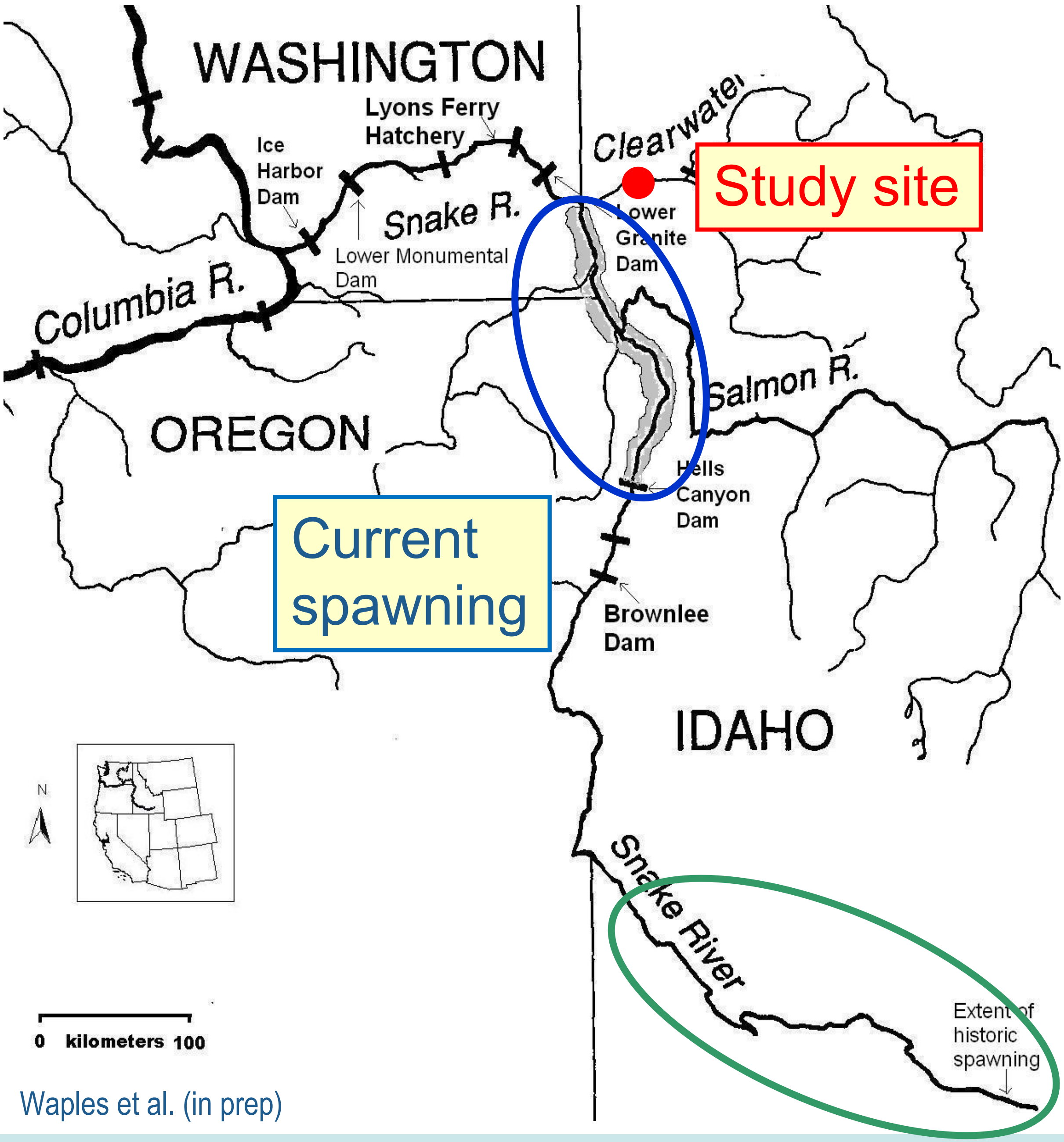
Residents produce migrants – but at what cost?



Thrower & Hard (2009)

- Residents can retain the ability to produce smolts in the face of selection
- But they have much higher marine mortality
- How do migrating offspring of residents affect anadromous productivity?

Snake River fall Chinook salmon (*O. tshawytscha*)



Historical spawning

ESA listed 1992

Waples et al. (in prep)

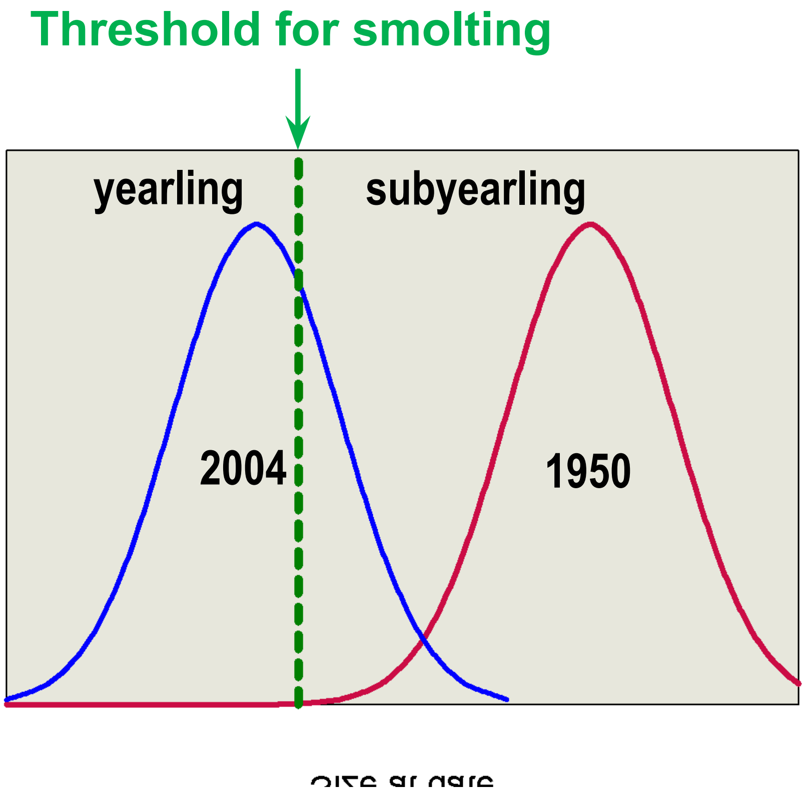
Life history changes in Snake River fall Chinook salmon

- Historically, nearly 100% subyearling migrants
- Recently, evidence for selection favoring yearling migrants (Williams et al. 2008)
- What happens if dams are removed?
  - If LH Δ reflects plasticity, perhaps not a problem
  - If LH Δ reflects evolution, population could be maladapted to its restored ecosystem

  - Important to maintain genetic diversity in age of seaward migrants

Changes in migrant age: plasticity or evolution?

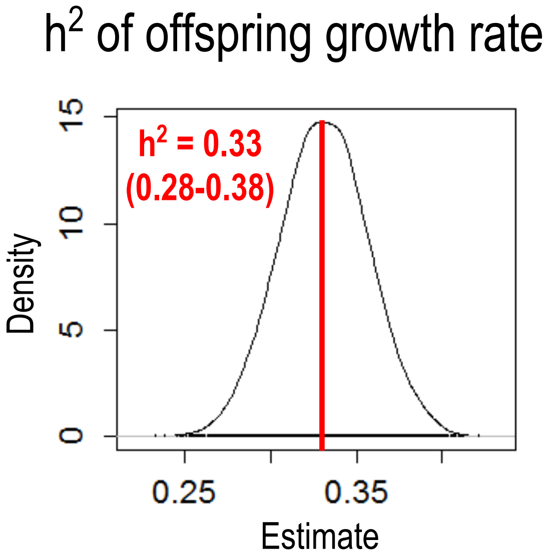
- The influence of dams on migrant survival has increased the frequency of yearling migrants
- This shift may reflect a plastic response alone to cooler temperature
- It could also reflect an evolutionary response to selection on smolt age (size) or growth



Myers & Hutchings 1986; Thorpe et al. 1998

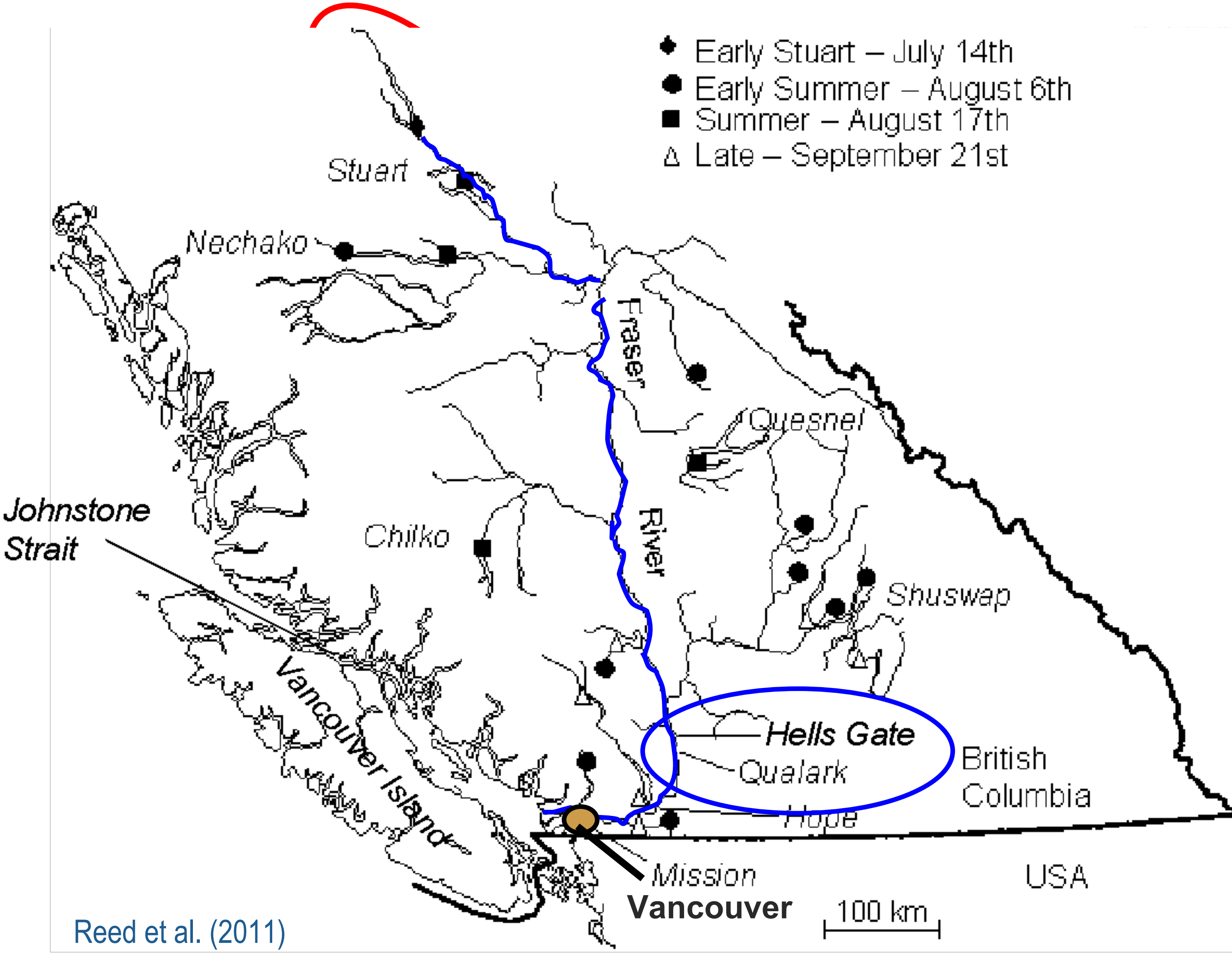
Heritability of smolt LH in fall Chinook salmon

- 3 year spawning matrix of known crosses (NPTH, Idaho)
- Parentage analysis to correlate parent with offspring LH
- Subyearling parents generally produced faster growing offspring than yearling parents
- Parents reared as yearlings in H produced fastest-growing offspring

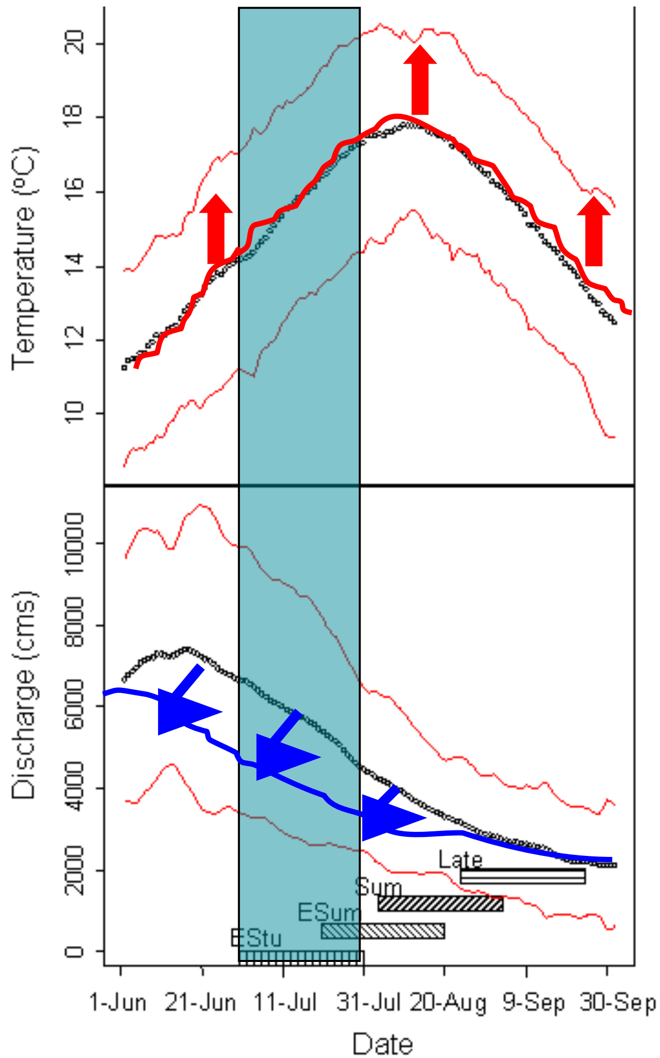


- Evolution might be involved in the observed life-history response

Fraser River, B.C. sockeye salmon (*O. nerka*)

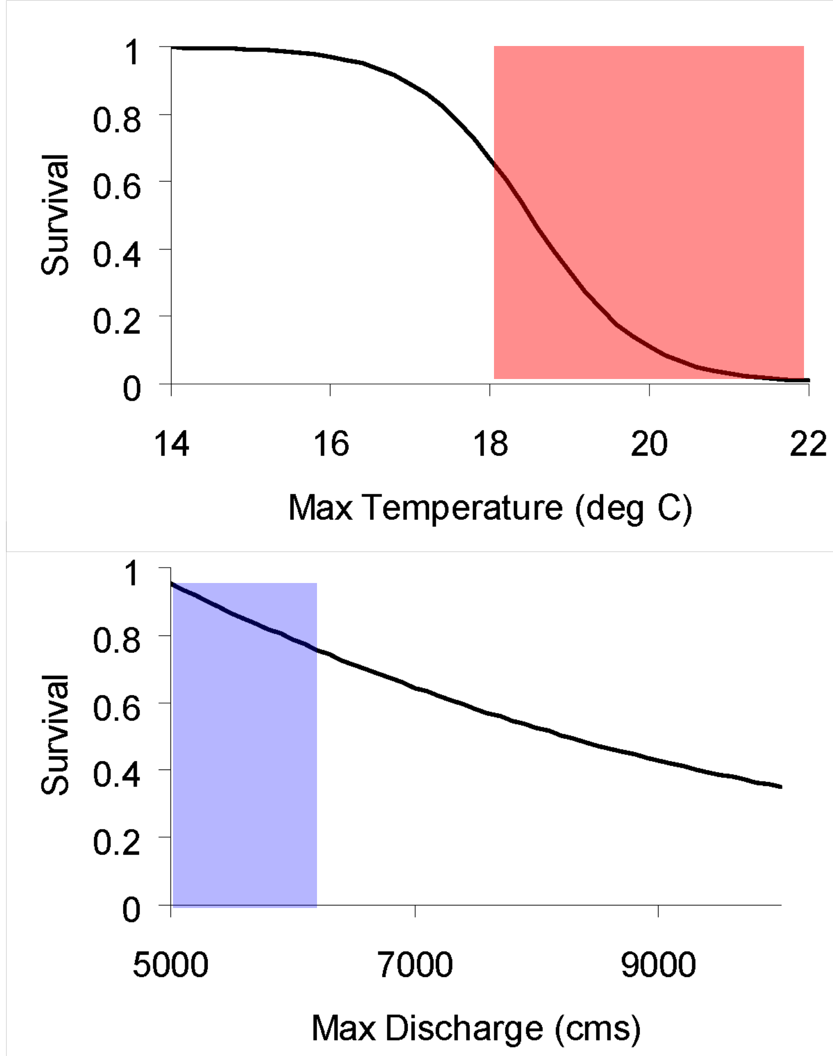


Temperature and flow patterns in upper Fraser R.

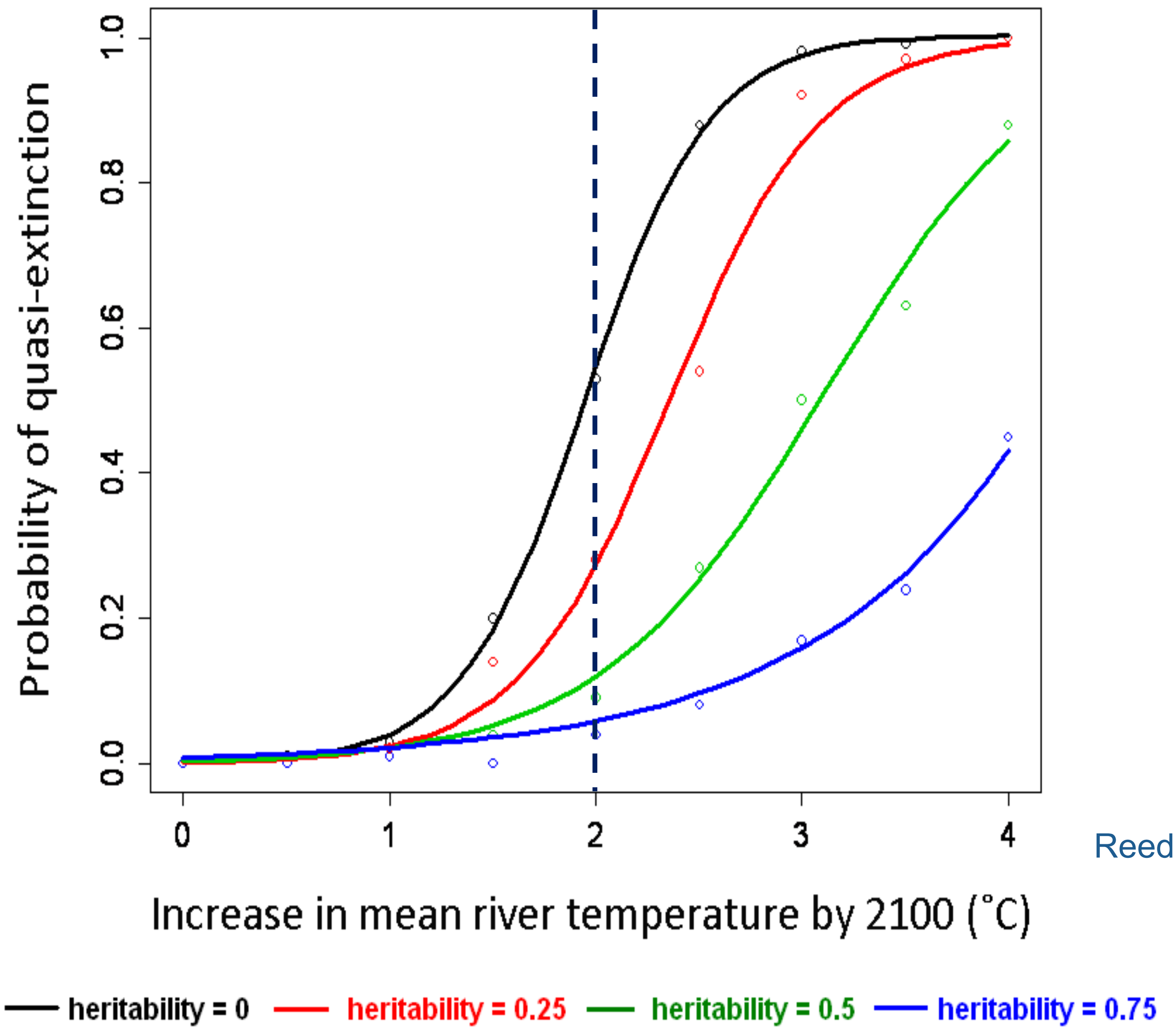


Est. survival functions

MacDonald et al. (2010)



Genetic rescue is feasible if h^2 is high enough



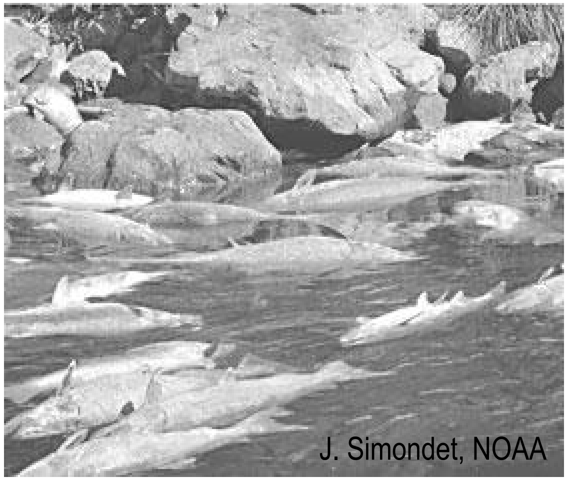
Reed et al. (2011)

Some key findings

1. Evolutionary demography of steelhead
   - Life history traits are heritable and under selection
   - Success of anadromous migrants depends on sufficient genetic variability but also on nature of past selection
2. Effects of the Columbia River hydropower system on salmon life history
   - Altered selective regimes have resulted in heritable life-history changes that can evolve in a few generations
   - These changes could be maladaptive in historical or restored habitat

Some key findings

3. Consequences of climate change for salmon
   - Climate change will probably narrow optimal windows for migration and reproduction
   - It will likely shift the seasonal timing of these optima as well
   - Ability of fish to adapt depends on the evolutionary capacity to respond to environmental change
     - ↑ temperature tolerance?
     - Δ phenology or dispersal


J. Simondet, NOAA

Related life-history studies at NWFSC & SWFSC

- Evolution of smolt age in hatcheries (Berejikian, Tue PM)
- Evolution of age at spawning in hatcheries (Ford, Tue PM)
- Climate change effects on adult migration timing (Crozier, Mon PM)
- Residency and anadromy in *O. mykiss* (Pearse, Satterthwaite)
- Epigenetics/genomics and LH expression (Swanson & Nichols)
- Phenotypic plasticity and cue reliability (Reed et al.)
- Fisheries- and predator-induced evolution (Hard et al.)
- Evolutionary response to climate change (Audzijonyte & Waples)

Other genetic research on protected species

- Current and historical population structure
- Mixed-stock fishery analysis
- Genetic effects of captive culture (domestication selection)
- Wild pedigree reconstruction and parentage assignment
- Effective population size and rates of genetic change
- Genetic identification of killer whale prey

Strengths

- Broad technical expertise in dedicated staff
  - Salmonid biology, ecology & evolution
  - Molecular, population and quantitative genetics & genomics
  - Experimental design & analysis
- Experience bridging evolutionary & ecological approaches
- Diverse collaborations with academics, government researchers, NGOs, stakeholders & independent scientists
- Technical products address NOAA's stewardship mission and scientific support is responsive to NOAA's administrative & regulatory needs

Challenges

- Many protected species are long-lived and difficult to study
- Suitable experiments are logistically challenging, often protracted, and expensive
- Our ability to collect critical information is being outpaced by the development of tools that can help us to answer the important questions
- Increasing FTE labor costs constrain operating funds
- Extensive reliance on contract labor; workforce demographics pose future challenges
- Travel restrictions make it difficult to collaborate efficiently between Centers and to sustain long-term field work

Opportunities

- Investigate the nature of selection on life history in threatened species and their responses to it
- Increase attention to evolutionary issues in protected species conservation (e.g., human-induced evolution)
- Enhance ability to address emerging questions with innovative, interdisciplinary approaches
- A few research questions to explore:
  - How much standing diversity is needed to maintain adaptive potential in threatened species?
  - How do we link evolutionary processes to population dynamics?
  - Can phenotypic plasticity ameliorate genetic adaptation to strong directional selection (e.g., from climate change)?

Acknowledgments

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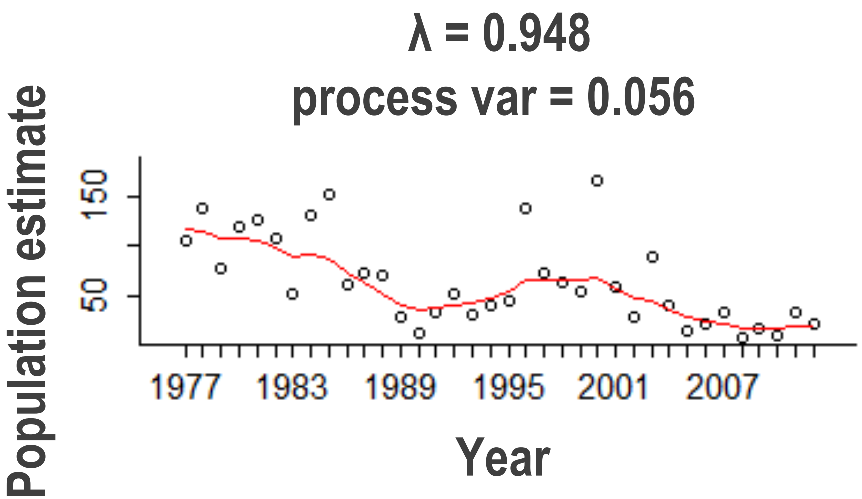
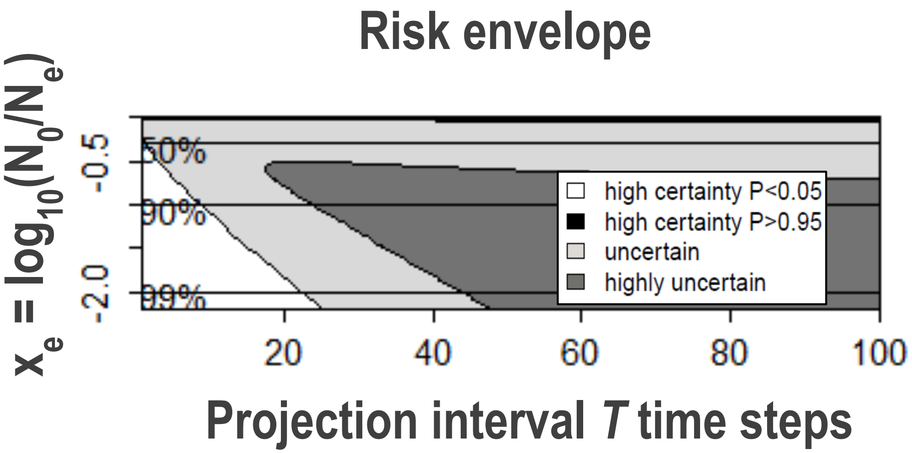
- Ben Hecht & Matt Hale (Purdue)
- Many other collaborators from NOAA, UW, OSU, CDFO, WDFW, ODFW, CRIFTC & tribal agencies

FIN

- Extra slides (for questions/discussion) here

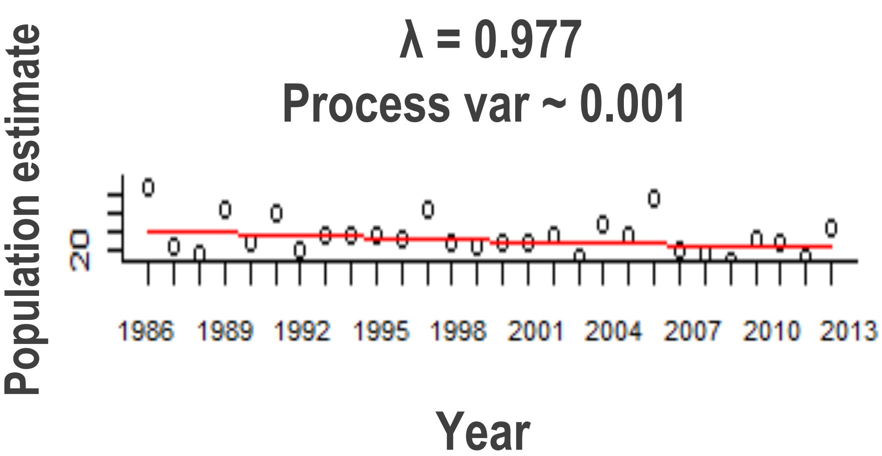
Abundance and extinction risk of Snow Creek steelhead

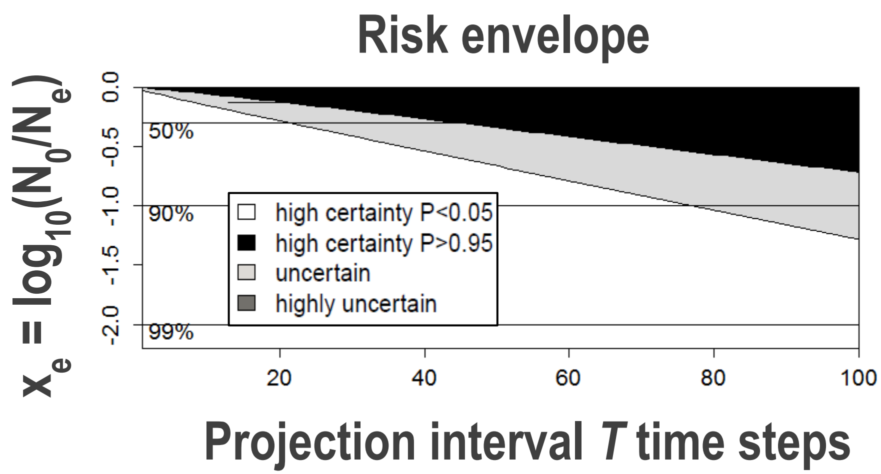




- No definitive evidence for declining productivity, but abundance has fallen
- Future abundance is unpredictable

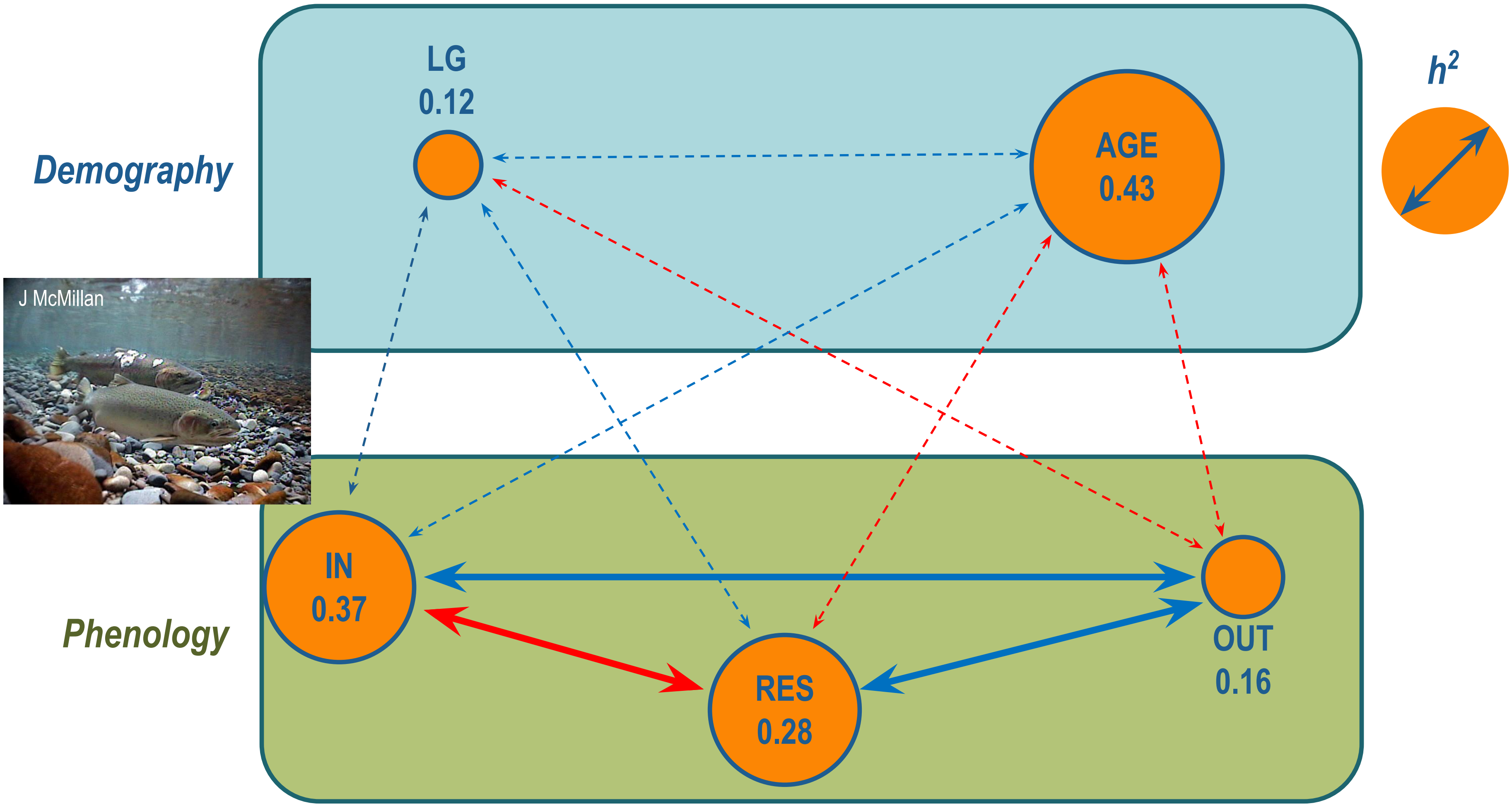
Abundance and extinction risk of Sashin Creek steelhead





- No evidence for declining productivity; abundance is low and stable
- Resident fish are abundant, but it isn't known how many smolts they produce

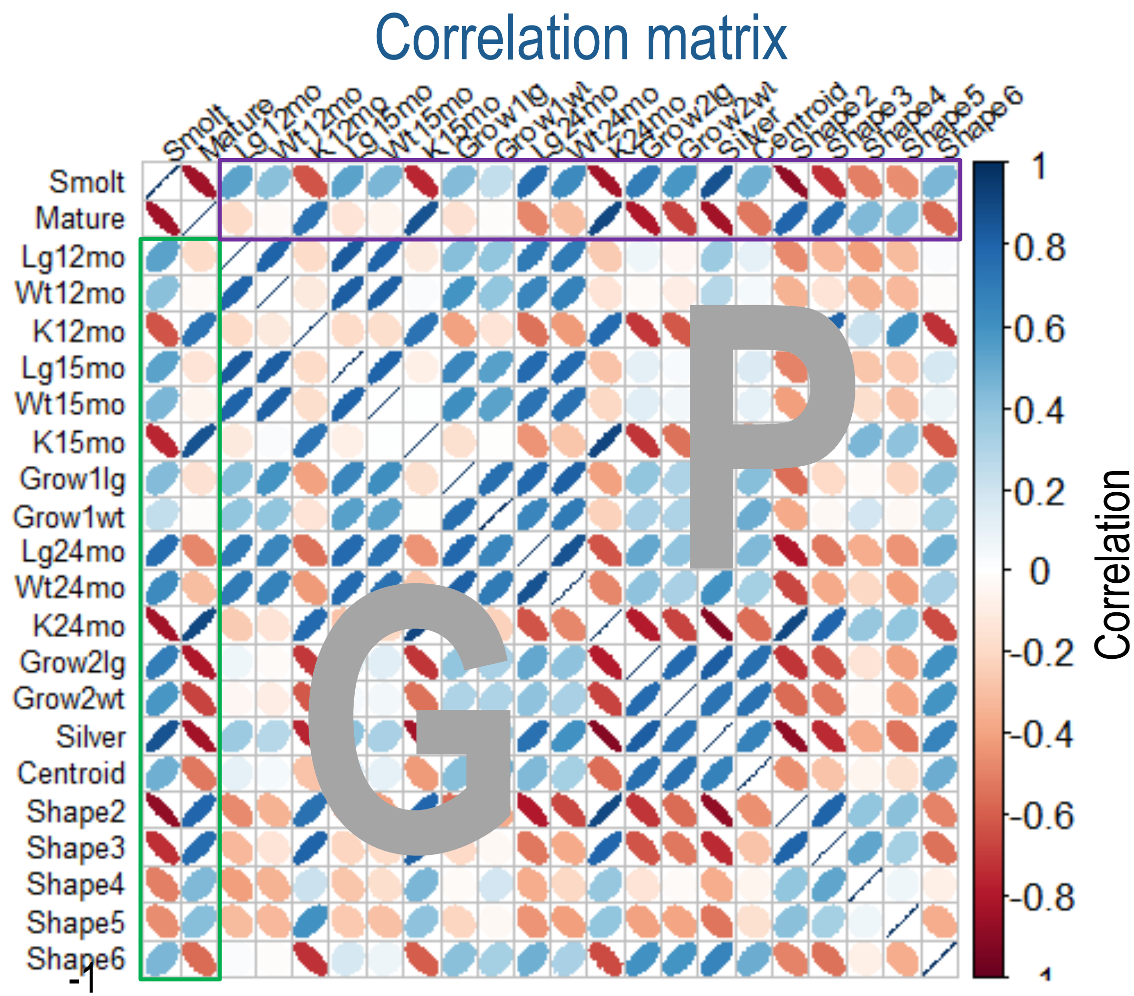
Evolution of life history in wild steelhead



- Size and run timing can and do respond to selection
- Adult phenology and stream residence covary and influence RS

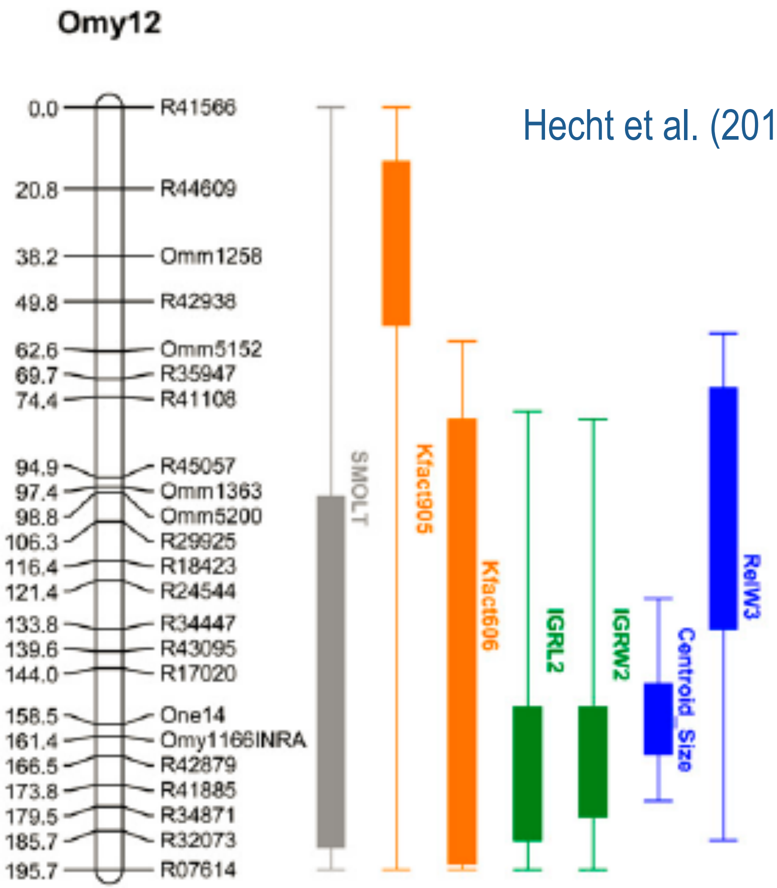
Architecture of juvenile *O. mykiss* life history

- Growth, size and shape are heritable and highly correlated
- QTL for these traits map to genomic sites known to influence migration propensity
- Resident and migratory trajectories appear to be highly canalized



Hecht et al. (2015)

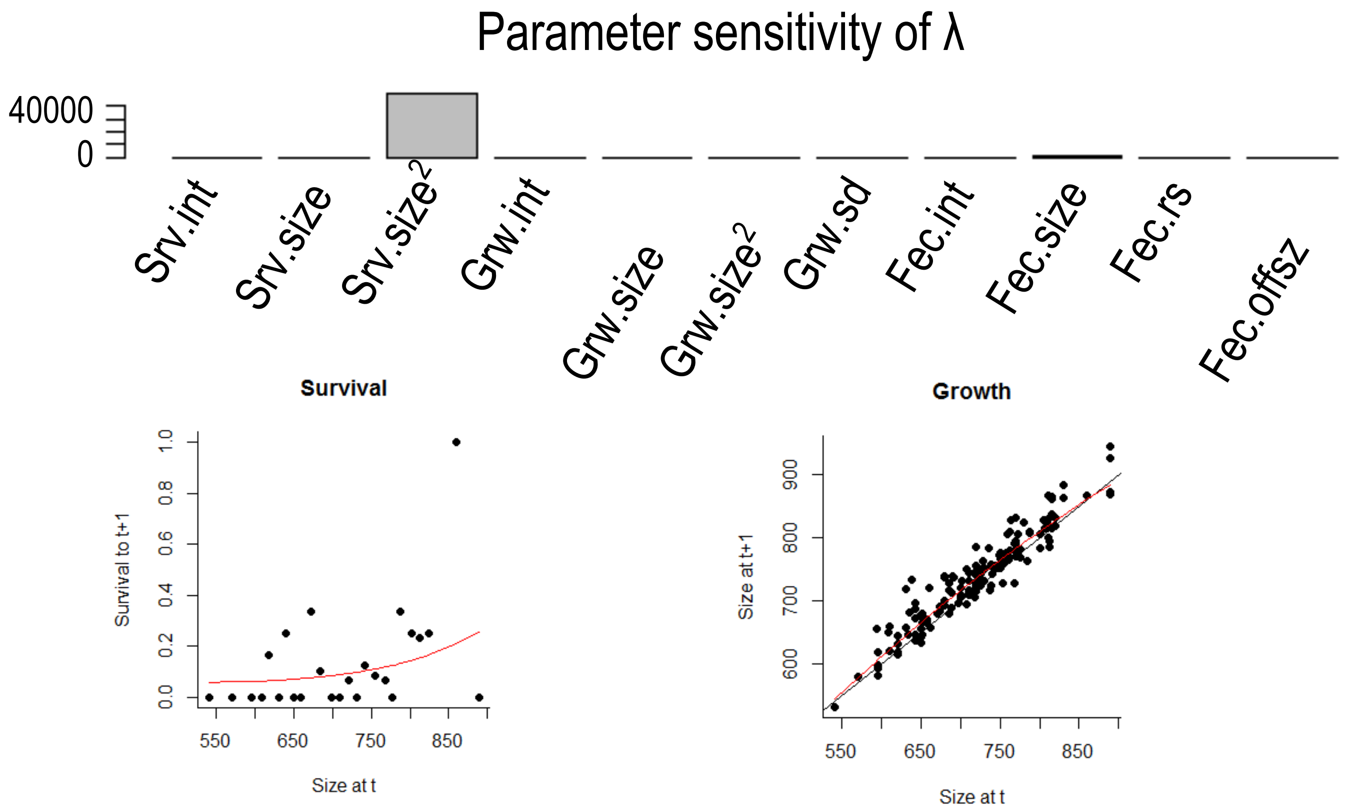
Steelhead smolt Quantitative Trait Loci



Hecht et al. (2012)

- QTL for traits associated with smolt metamorphosis map to specific linkage groups

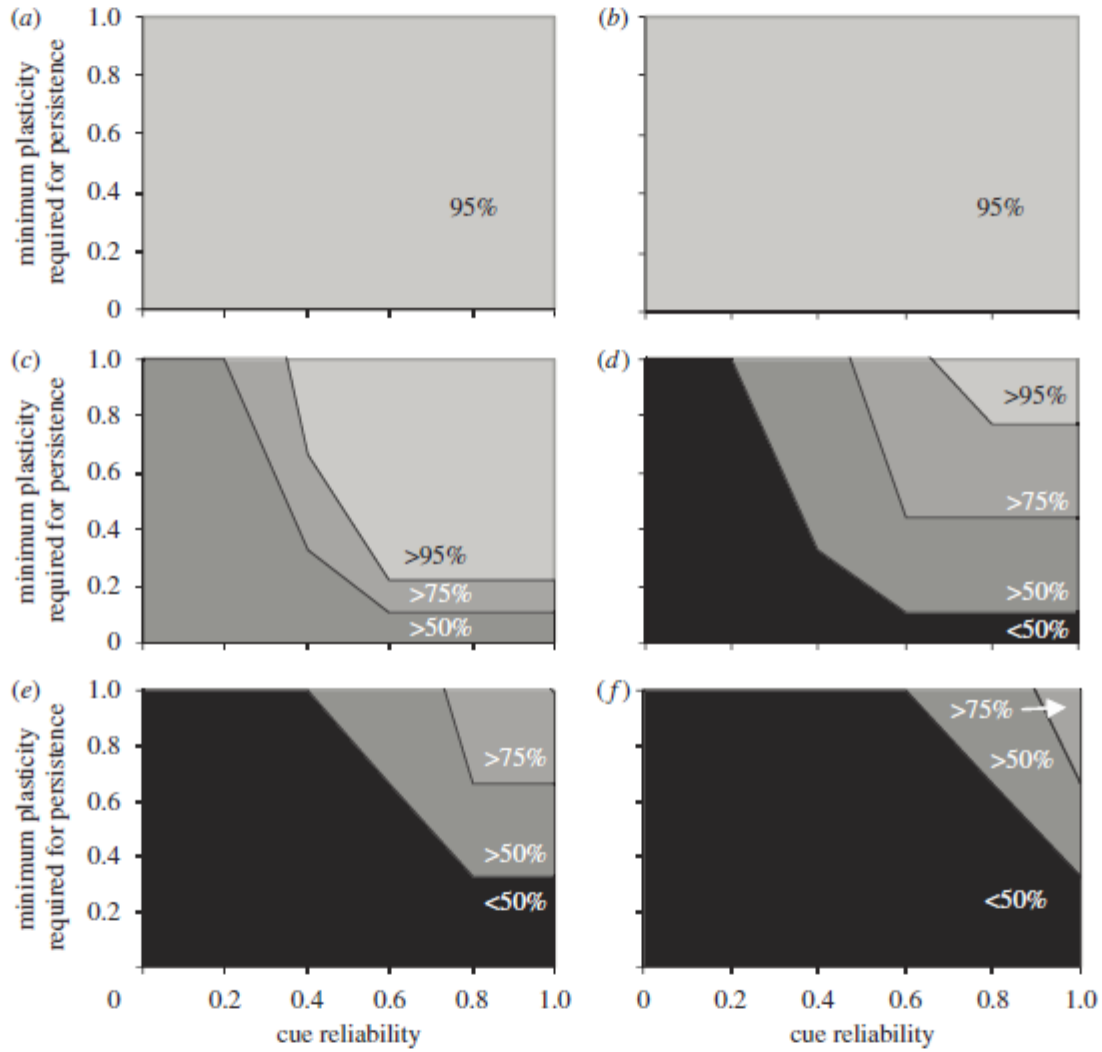
Size transitions can drive population dynamics



- Population growth is sensitive to the way that size influences annual marine survival, fertility and reproductive success

Plasticity and persistence

- Plasticity allows greater likelihood of persistence, particularly in highly unpredictable environments
- However, the environmental cue must be sufficiently reliable



Reed et al. (2010)